Great Principles of Computing

Peter J Denning

- What is computation?
- What contribution is our field?
- What is relation to other science and engineering?

Take-Away Claims

1. Computing has caused a revolution in science.
2. The great principles framework reveals timeless principles transcending technology.
3. Current issues regarding enrollments and recognition are being resolved.

Claim 1:
Revolution in Science

- 1940's: Computers as tools in science
- 1980's: Computing as a method of science
- 2000's: Computation a process of nature

"Computer Science differs from physics in that it is not actually a science. It does not study natural objects. Neither is it mathematics. It's like engineering -- about getting to do something, rather than dealing with abstractions."

--Richard Feynman (1983)

"Biology is today an information science. The output of the system, the mechanics of life, are encoded in a digital medium and read out by a series of reading heads. Biology is no longer solely the province of the small laboratory. Contributions come from many directions."

-- David Baltimore (2001)

Computing is fomenting the revolution.

What is computing?

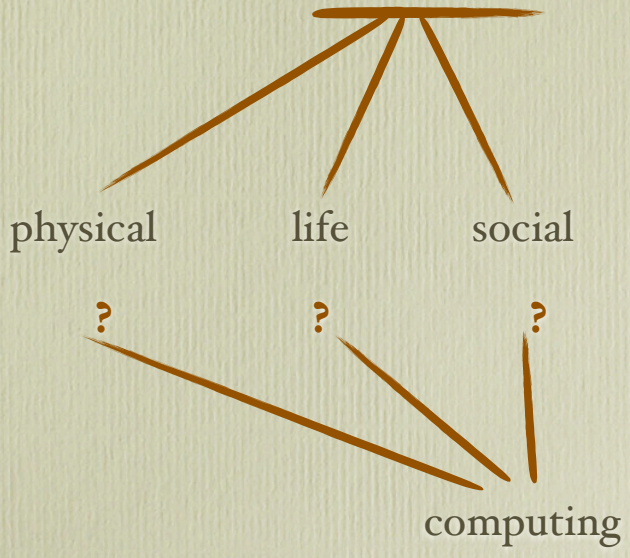
- 1930's: what a person does when calculating
- 1940's: what an automatic computer does
- 1960's: phenomena surrounding computers
- 1970's: what programs and algorithms do
- 1980's: what can be automated
- 1990's: transformation of information processes

Computing has many interactions with all other fields.

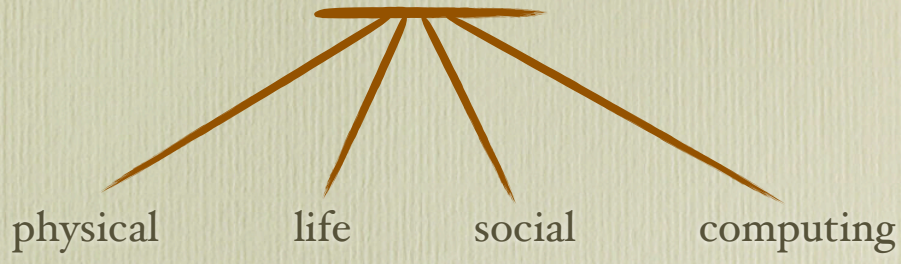
implementations

influences

Fourth Great Domain of Science?



Fourth Great Domain of Science?



(Paul Rosenbloom)

pre-revolution

Our tradition says:

Computer Science is
the study of phenomena
surrounding computers.

And the revolution says:

Computing
is the study of
natural and artificial
information processes.

(And may be fourth
great domain of science)

Claim 2:
Principles Framework

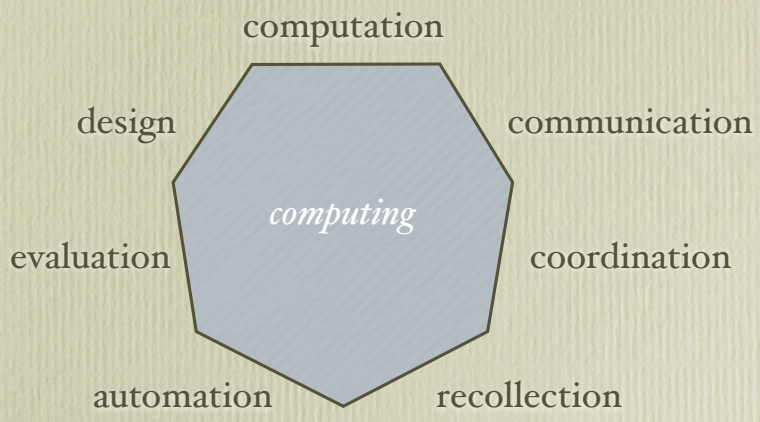
Objectives

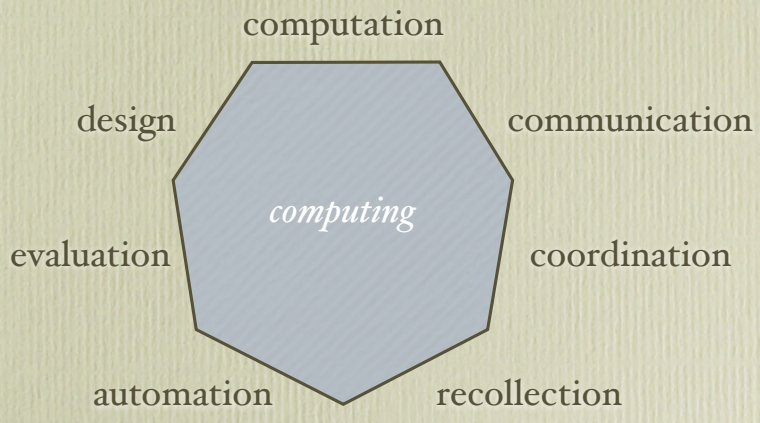
- Deep structure of computing field
- Timeless principles transcending technology
- Foster innovation by revealing connections
- Common language for computation among fields
- Reveal the magic and beauty
- Inspire young people

A Taxonomy of Principles

- Seven Categories (overlapping)
- Principles within categories (only examples here)

The Seven Categories





Mechanics

programming

systems thinking

computational thinking

modeling and experimenting

building and testing

Practices

Examples

Not enough time here to examine each category in detail

- UPS delivery routing
- Compression
- Cosmic Ray computer crashes
- Action loops
- Locality
- No fault insurance

More effective action in the World

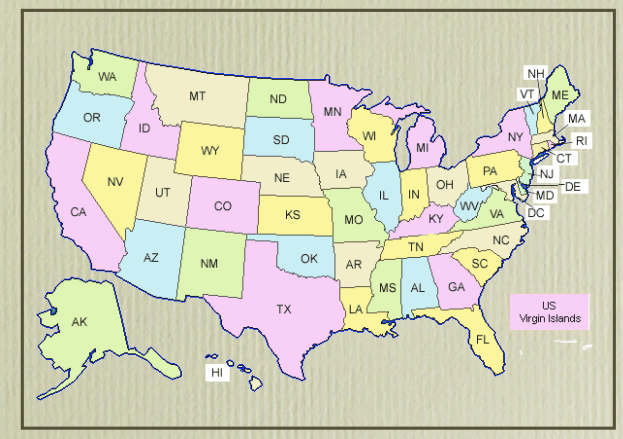
World teaching us how to compute

UPS Delivery Routing

Computation

- N cities
- Shortest path visiting each once
- Is there a path of length < L?

UPS Delivery Routing



What is shortest path visiting capital of each state once?

UPS Delivery Routing

- Only known algorithms take time N^N.
- For 50 stops, this is about 10^{85} .
- A computing machine operating at 1 teraops/sec would provide require about 10^{66} years. The universe is only about 10^{10} years old.
- The problem is “intractable”.

UPS Delivery Routing

- Class “NP” over 3000 common problems
- Fast check, slow solution
- Fast for one, fast for all
- Class “NP”
- Heuristics

Compression

Communication

Representations

- String in a language standing for an entity
- Currency of computation
- Carry information

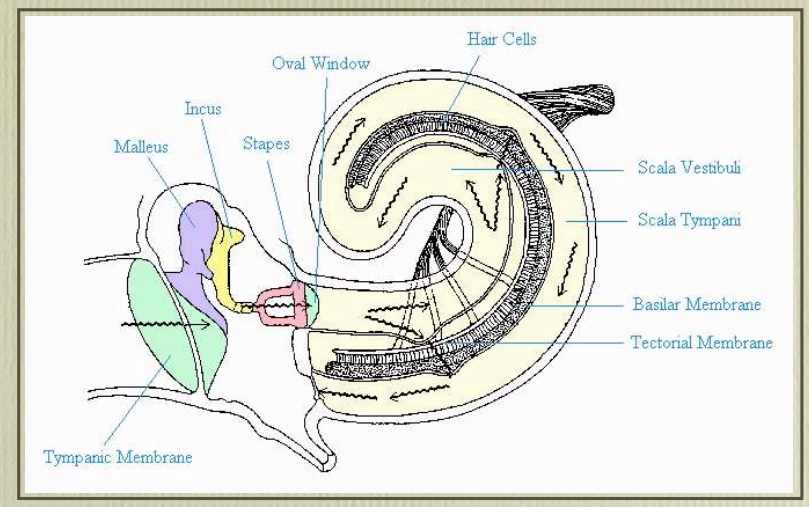
Shortening Them

- Can we compress representations? Yes.
- Can we find much shorter representations? Yes.
- Can we find the shortest representation? No.
  It is unknowable.

MP3

- Derived from operation of cochlea, enabled a new music distribution industry
- Typical uncompressed song is about 40 Mb
- MP3 compressed is about 4 Mb
- Fit 2500 songs on 1 Gb hard disk

MP3 derives from operation of cochlea.



Many hairs, different lengths, vibrate at different frequencies

MP3 deletes frequencies ear cannot hear.

Cosmic Ray Crashes

Coordination

Mysterious Crashes

- Computer hardware freezes occasionally
- “Cosmic rays” alleged
- Normal after restart
- Only when interrupts on
- Solution from a philosophical dog.

Selecting Alternatives

- Buridan's dog.
- Sidewalk collision avoidance.

Selecting Alternatives

- Buridan's dog.
- Sidewalk collision avoidance.

Selecting Alternatives

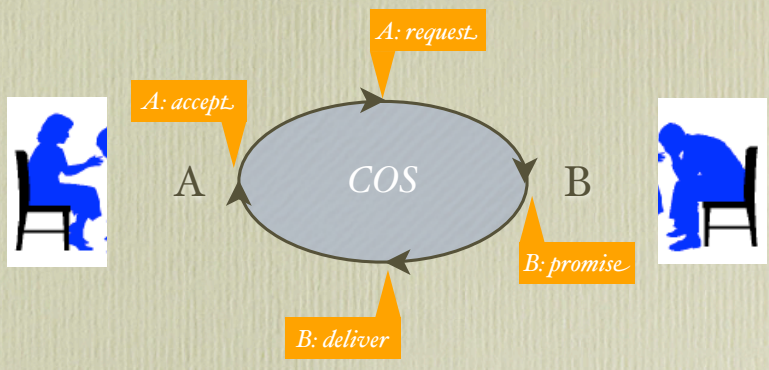
- Choice uncertainty principle: selection ambiguous if forced within a deadline
- Interrupt decision circuitry
- Turn off clock until decision made!
- Brain uncertainty during decision making: information overload

Action Loops

Coordination

Alice
A

Bob
B



The fundamental building block of all coordinations.

A or B or both can be a computer.

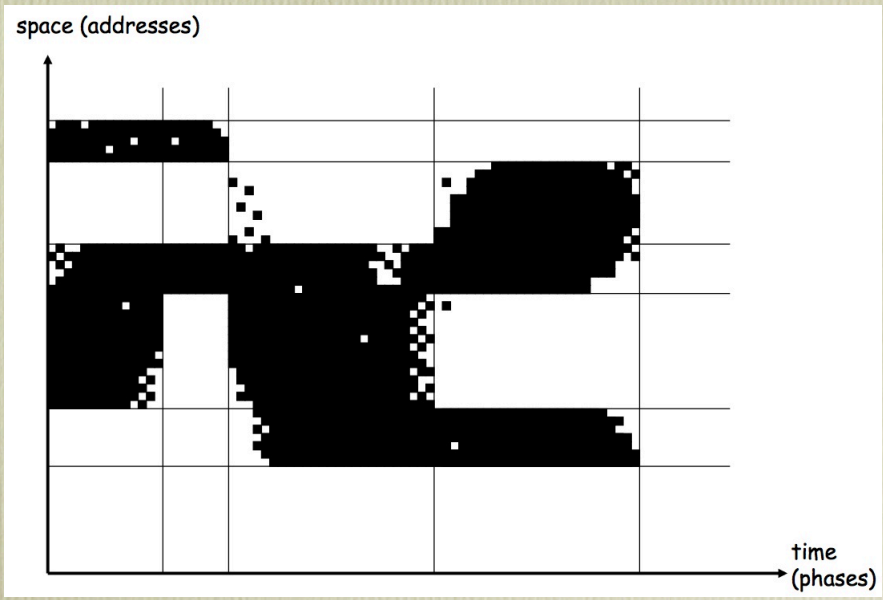
Action Loops

- Natural
- Computational
- Hybrid
- Coordination games: collective intelligence

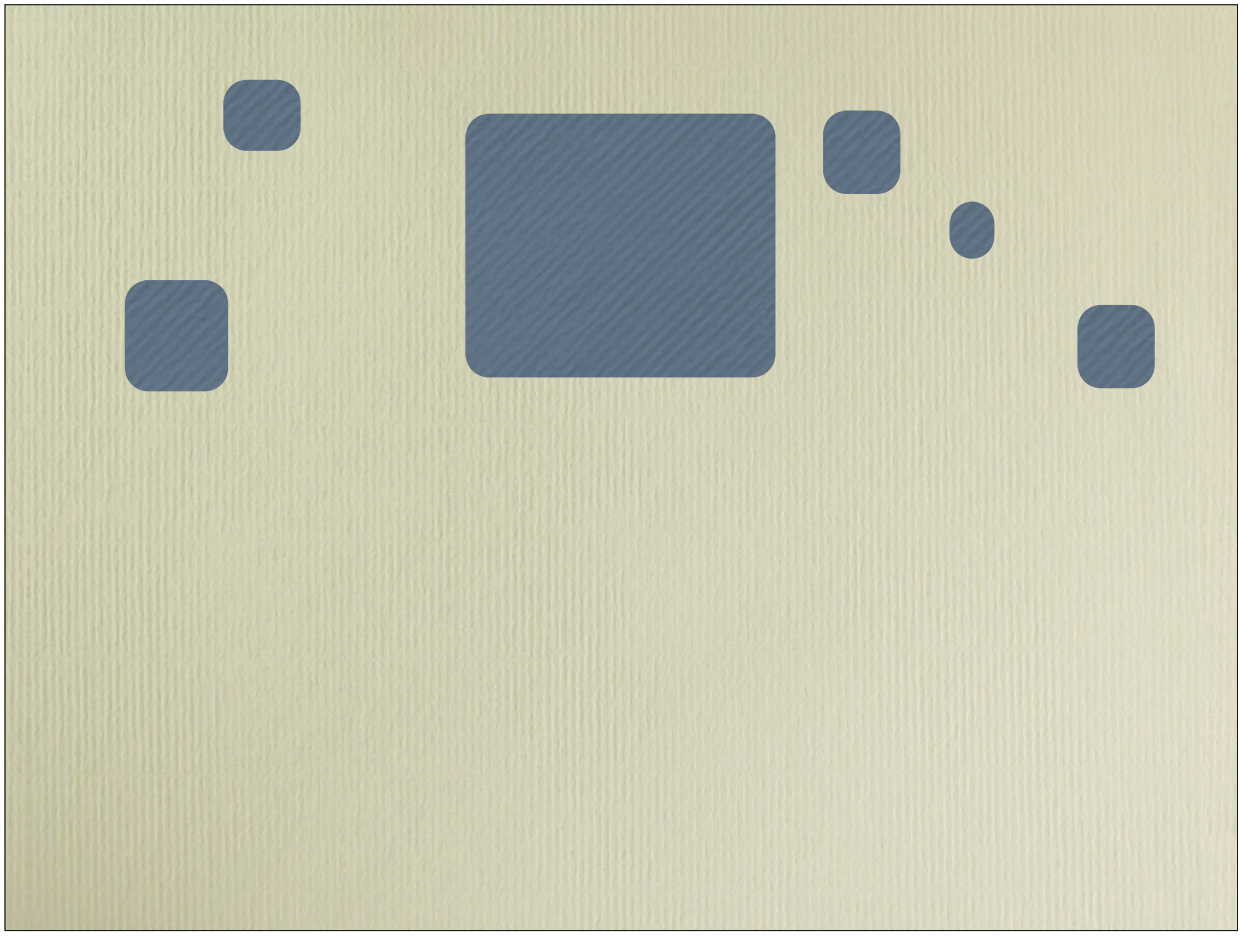
Locality

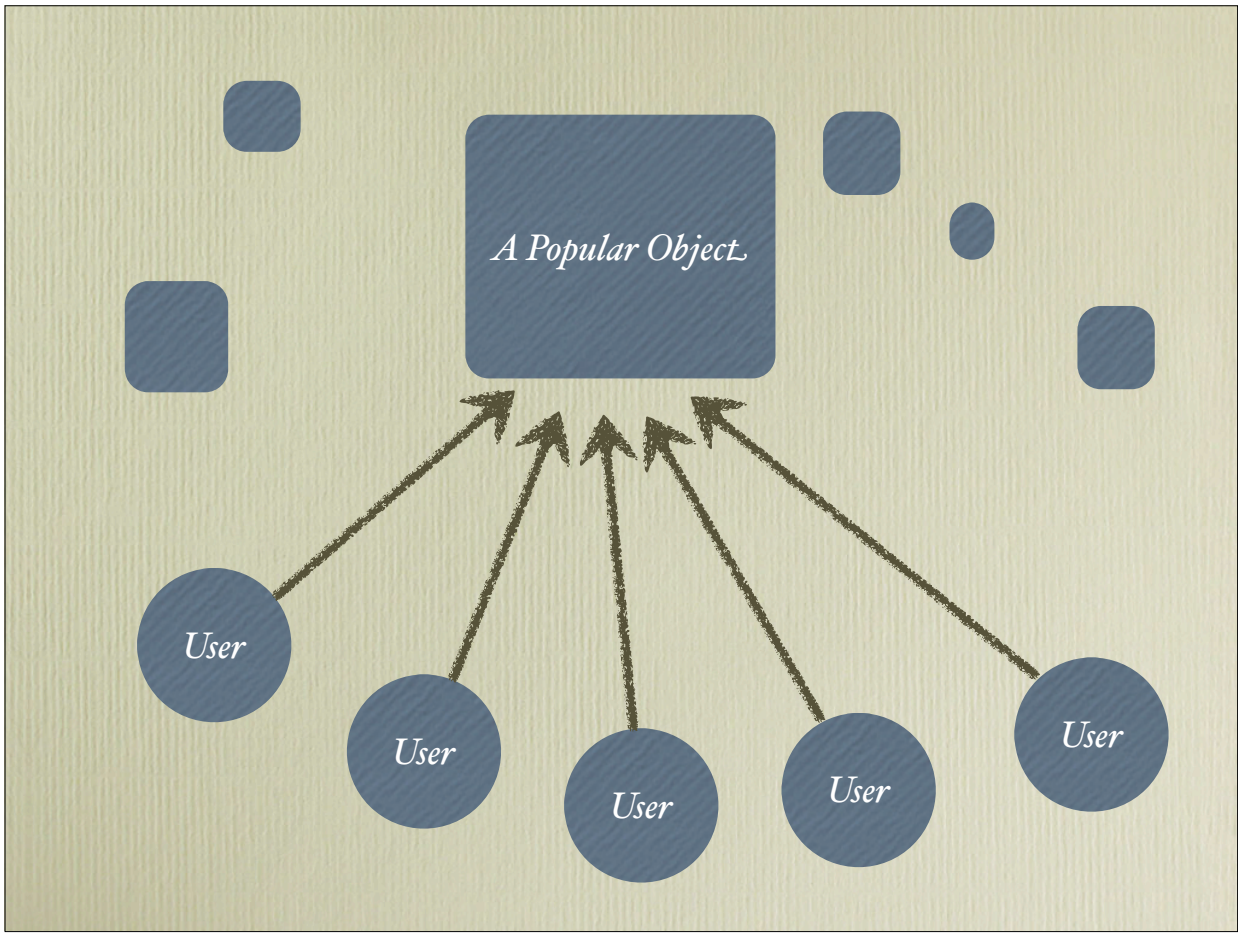
Recollection

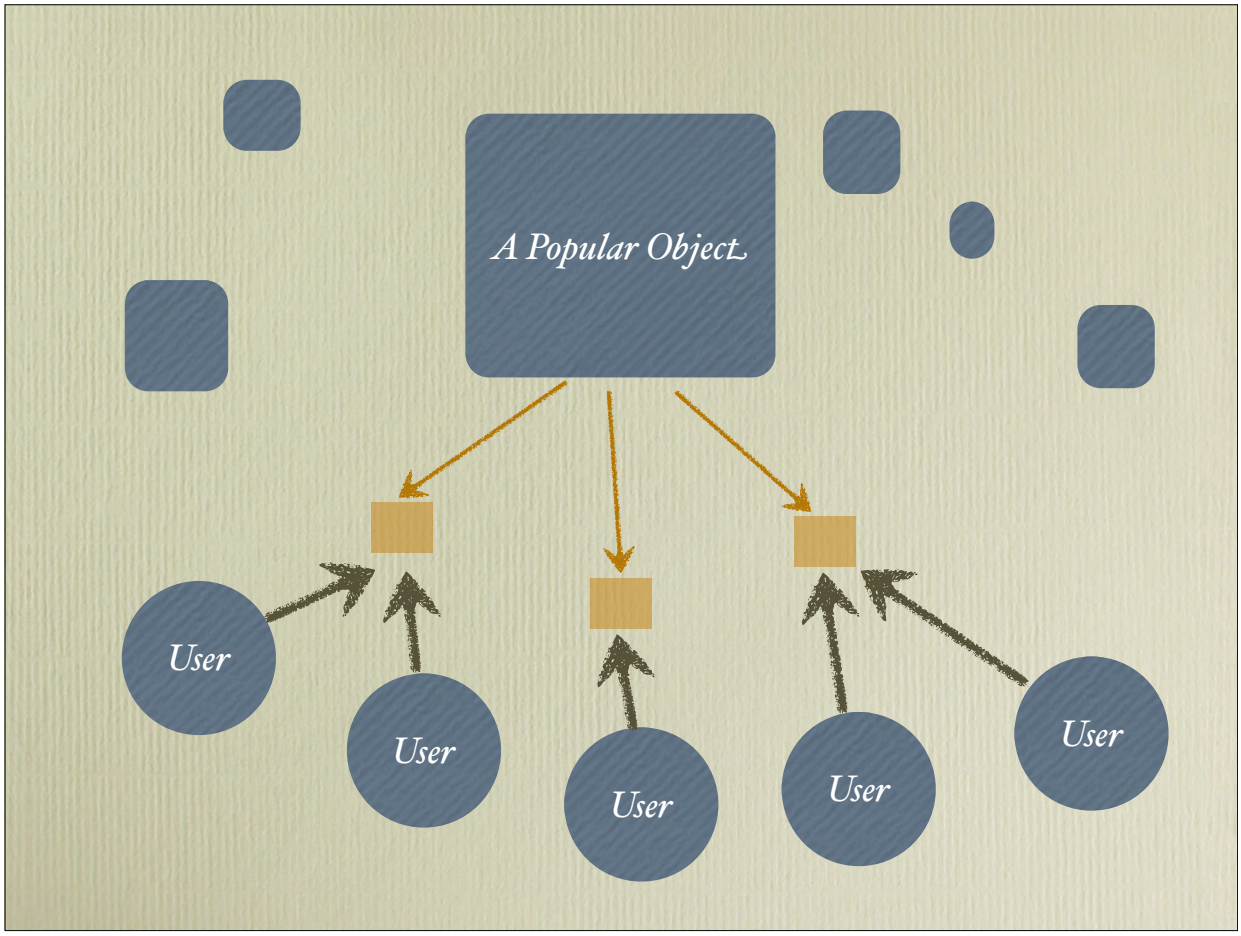
Reference Map



- Immediate past predicts immediate future
- Near optimal memory management
- Hardware caches
- Internet caches
- No memory space is flat!



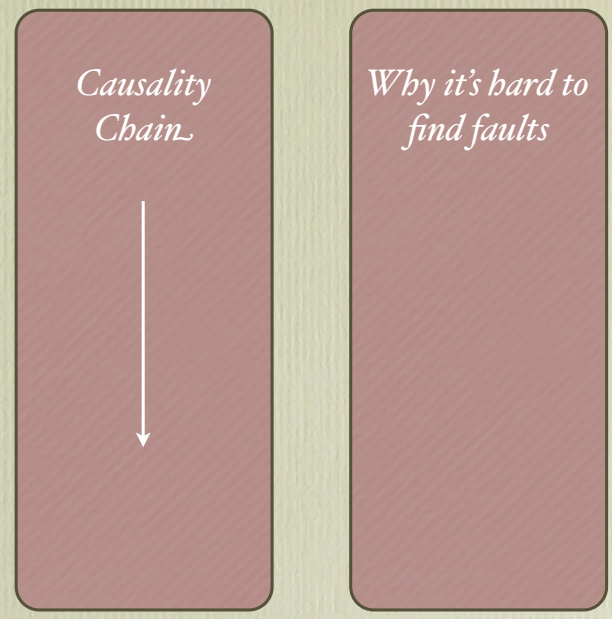

A Popular Object
User
User
User
User
User



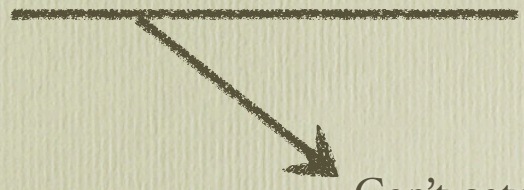
No Fault Insurance

Design

- Failure
- Error
- Fault



- Line of defense 1: fault tolerant architecture
- Line of defense 2: programming, compiling



Can't catch

- object code TH
- hardware TH

- Things architecture can do easily
  - Bounds checking
  - Access checking
  - Atomic transactions
  - Backward error recovery
  - Forward error recovery

Summary of Examples

- Delivery routing (computation)
- Compression (communication)
- Cosmic ray crashes (coordination)
- Action loops (coordination)
- Locality (recollection)
- No fault insurance (design)

- Many “non-theory” principles
- Many interactions deep into other fields

Claim 3:
Struggles with enrollments and recognition are being resolved.

- Current issues
  - Abstraction
  - Computational thinking
  - AP course
- Relax: It's happening by itself!

Actions

- GP web site (greatprinciples.org)
- GP course (NPS)
- GP book
- GP Partnerships: CS Unplugged, LabRats
- Field Guide Project (NSF, ACM)
- Ubiquity symposium

What we said

1. Computing has caused a revolution in science.
2. The great principles framework reveals timeless principles transcending technology.
3. Current issues regarding enrollments and recognition are being resolved.

In 1936, Alan Turing showed
mathematicians they could not avoid
computing, as much as they might try.
He was right -- not only for mathematics,
but for all of science and engineering.

The important thing is not to stop questioning.
It is enough if one tries merely to comprehend
a little of the mystery every day.

-- Albert Einstein

I have a deep regret that I did not proceed
far enough at least to understand something
of the great principles of mathematics, for
men thus endowed seem to have an extra sense.

-- Charles Darwin

These are my principles, and if you don't like them ... well, I have a few others.

-- Groucho Marx

Great Principles of Computing

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Traditional Technology View

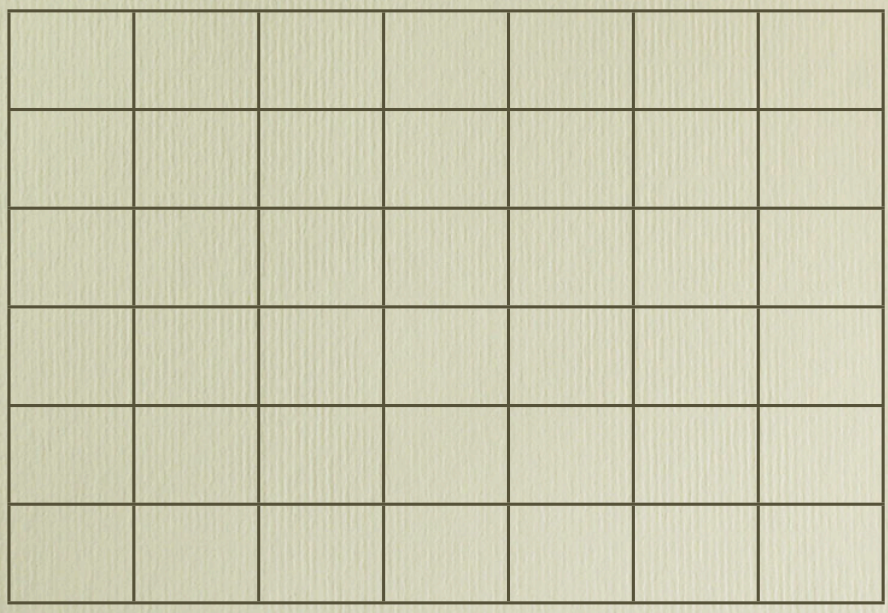
- ACM 1989: 9 categories
- ACM 2001: 14 main categories, 130 subcategories
- ACM Ontology Project 2006: ?? categories

Unified View

2-D matrix

Categories

Topics



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arch							
netw							
security							
data base							
virtual mem							
progr lang							

	comp	comm	coord	recoll	auto	eval	design
arch							
netw							
security			key distribution protocol				
data base							
virtual mem							
progr lang							

	comp	comm	coord	recoll	auto	eval	design
arch							
netw							
security	encryption functions	secrecy authentication covert	key distribution, 0KP	confinement partitioning ref monitor	intrusion det biometric ID	protocol performance under loads	end-to-end layered virtual mach
data base							
virtual mem							
progr lang							

	comp	comm	coord	recoll	auto	eval	design
arch			hardware handshake				
netw			TCP/IP				
security			key distribution				
data base			atomic transaction				
virtual mem			page fault interrupt				
progr lang			semaphores monitors				